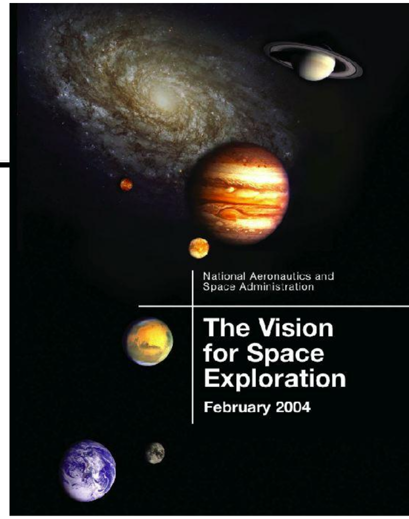
Human & Robotic Technology

to Enable Future Space Flight Capabilities
and Realize the U.S. National Vision for Space Exploration



2004 NASA/DoD Conference on Evolvable Hardware
June 24-26, 2004
Seattle, Washington, USA

24 June 2004

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2004 President's Vision for Space Exploration
A New Future for U.S. Civil Space Programs

"This cause of exploration and discovery is not an option we choose; it is a desire written in the human heart."

President George W. Bush
February 4, 2003

"We leave as we came, and God willing as we shall return, with peace and hope for all mankind."

Eugene Cernan (Commander of last Apollo mission)
December 17, 1972

". . . America will make those words come true."

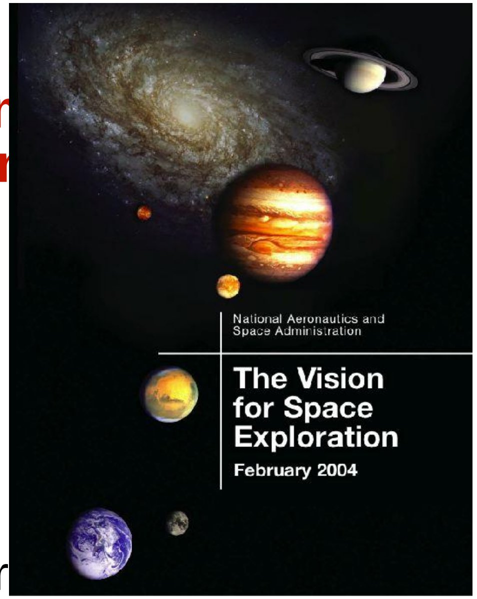
President George W. Bush
January 14, 2004

- **On January 14, 2004, President Bush articulated a new Vision for Space Exploration in the 21st Century**
- **This Vision encompasses a broad range of human and robotic missions, including the Moon, Mars and destinations beyond**
- **It establishes clear goals and objectives, but sets equally clear budgetary 'boundaries' by stating firm priorities and tough choices**
- **It also establishes as policy the goals of pursuing commercial and international collaboration in realizing the new vision**

- ***Advances in Human and Robotic Technology will play a key role as enabler and major benefit of the new Vision…***

Goal and Objectives

- **The fundamental goal of this vision is to advance U.S. scientific, security and econor interests through a robust space exploratio program.**
- **In support of this goal, the United States will:**
  - Implement a sustained and affordable human and robotic program to explore the solar system and beyond;
  - Extend human presence across the solar system, starting with a human return to the Moon by the year 2020;
  - Develop the innovative technologies, knowledge, and infrastructures both to explore and to support decisions about the destinations for human exploration; and,
  - Promote international and commercial participation in exploration to further U.S. scientific, security, and economic interests



Bringing the Vision to Reality

Exploration Activities in Low Earth Orbit

- **Space Shuttle**
  - Return the Space Shuttle to flight as soon as practical, based on the recommendations of the CAIB
- **International Space Station**
  - Complete assembly of the International Space Station (ISS), including U.S. components that support U.S. space exploration goals and those provided by foreign partners, planned for the end of this decade
- **The Moon**
  - Starting no later than 2008, initiate a series of robotic missions to the Moon to prepare for and support future human exploration activities;
- **Mars and Other Destinations**
  - Conduct robotic exploration of Mars to search for evidence of life, to understand the history of the Solar System, and to prepare for future human exploration
- **Space Transportation Capabilities Support Exploration**
  - Develop a new crew exploration vehicle to provide crew transportation for missions beyond low Earth orbit;
- **International and Commercial Participation**
  - Pursue commercial opportunities for providing transportation and other services support the International Space Station and exploration missions beyond low Earth orbit

"We are developing a robust, integrated exploration strategy to guide our investments. Through our new building block capabilities and scientific discoveries, we are creating stepping stones to the future…"

Problem Statement

- **For current space systems, how do we:**
  - reduce complexity
  - reduce design, build, and test times
  - reduce cost
  - increase flexibility to satisfy multiple functions
  - make them practical for widespread human and robotic exploration

- **Solution …**

Modular, Reconfigurable, Rapid Space Systems

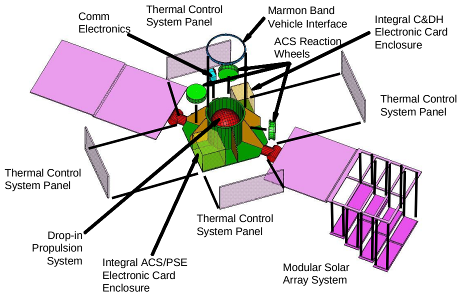
– Modularity:
  – Allows for interchangeable components

• Re-configurability:
  – Allows for functional flexibility

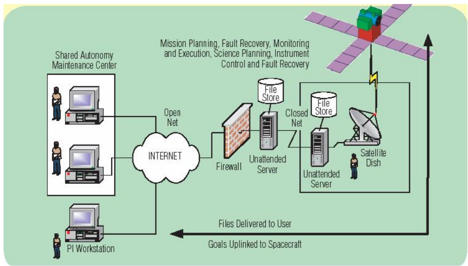
Space Platforms

• Rapid response:
  – Allows for quick integration & test and reduced cost

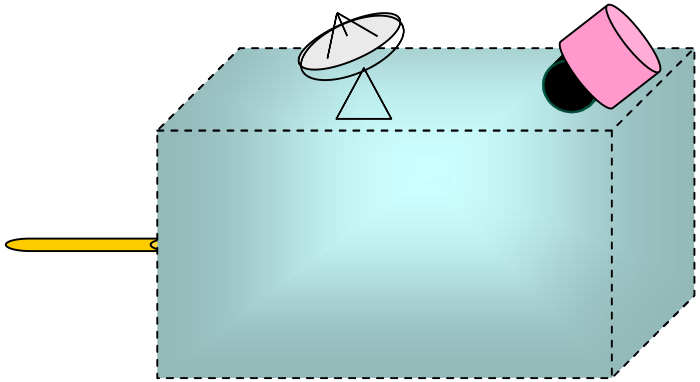
Space Segment



Ground Segment

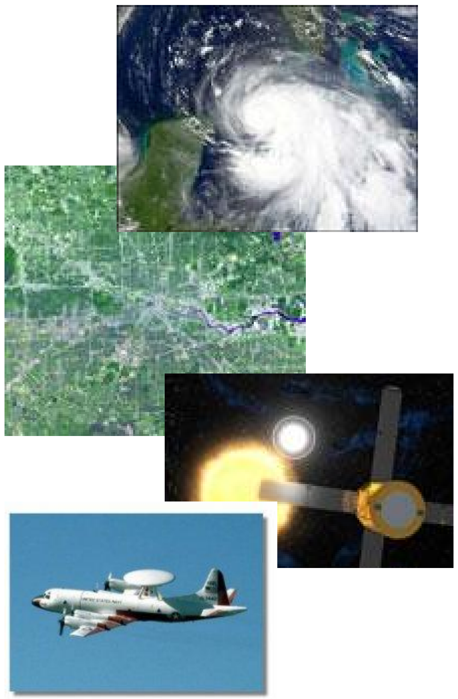


Modular, Reconfigurable, Systems



Modular and Evolvable

Selectable electro-mechanical and software components that may be re-used in quantized numbers. Must be capable of evolving to incorporate advances in technology. Must accept plug-and-play principles (e.g. Personal Computers). Collectively (and possibly individually) must result in intelligent units.

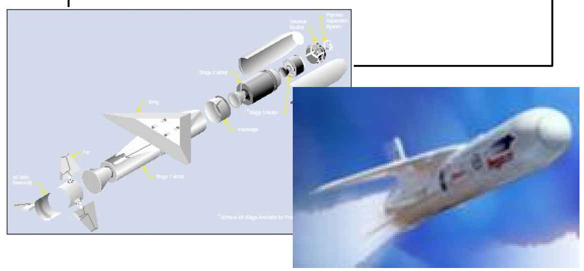


Reconfigurable

Must be capable of morphing in order to apply to a host of missions. Must be easy to produce, integrate, test, and launch. Must be capable of operating alone or as a collective part, physically detached or attached.

Rapid Response

Requirement-to-launch from days (< 7), to months (< 12), depending on application and needs.



Human & Robotic Technology
"System-of-Systems" Challenges: Mapping

Reliability/Safety

Affordability

Effectiveness

Margins/Redundancy	How may we improve reliability and safety at all levels through increased redundancy and common, readily integrated spares?
Modularity	How may we improve reliability and safety at all levels through the application of modularity and common, readily integrated spares?
In-Space Assembly	How may we increase reliability and safety through 'flexibility' by enabling the capability to reconfigure and repair systems?
Pre-positioning of Logistics	How may we increase reliability and safety through 'flexibility' by enabling the capability to pre-position systems, consumables and spares?
Power-/Energy-rich Operations	How may we increase reliability by assuring the power and energy are abundant (rather than scarce) for all key applications?
Reusability	How may we minimize the risks associated with 'first use' of systems, and the burden of extensive testing of new subsystems and systems?
Autonomy	How may we increase reliability and safety through more locally self-reliant systems and operations?
Precision Access	How may we improve safety and reliability of planetary operations in hazardous venues when logistics/systems may be delivered over time?
Virtual Presence	How may we increase safety through tele-medicine, and reliability through remote, high-quality engineering?
Space Resources	How may future missions be made safer and more reliable at the mission level through the availability of space resources?

Human & Robotic Technology
"System-of-Systems" Challenges: Mapping

Reliability/Safety

Affordability

Effectiveness

Margins/Redundancy	How may we lower life cycle costs through increased subsystem- and system- level margins and redundancy?
Modularity	How may we dramatically lower the cost of hardware, software; and reduce the no. of unique elements?
In-Space Assembly	Is it possible to effectively and reliability pursue space exploration using a "national" launcher(s) approach (rather than a unique system)?
Pre-positioning of Logistics	Is it possible to use high-efficiency propulsion to pre-position mission logistics 'cheaply'?
Power-/Energy-rich Operations	How may we be 'energy' and 'power' rich in our space exploration operations/systems?
Reusability	Is it possible to significantly reduce the need for diverse systems through hardware and software 'reuse'?
Autonomy	How may we realize the goal of a smaller/ lower operations team/costs?
Precision Access	How may we improve the chances of operational mission success (lower risk-related costs) in planetary excursions?
Virtual Presence	How may we establish a 'virtual presence' for critical medical and engineering personnel (rather than a physical presence)
Space Resources	How may we improve the affordability of mission operations through the use of local resources?

Human & Robotic Technology
“System-of-Systems” Challenges: Mapping

Reliability/Safety

Affordability

Effectiveness

Margins/Redundancy	How may increased margins and redundancy (at various levels) allow future operations that are more robust and flexible--and which accomplish more than otherwise?
Modularity	How may we increase effectiveness by making it easier to reconfigure systems an software to adapt to changing needs?
In-Space Assembly	How may we deploy and operate future ‘systems-of-systems’ that are larger than those possible with a single launch?
Pre-positioning of Logistics	How may we increase mission effectiveness through local refueling and re-supply using pre-positioned systems and vehicles?
Power-/Energy-rich Operations	How may we enable more ambitious mission operations and objectives through increased local power/energy in diverse venues?
Reusability	How may we most cost-effectively employ each deployed system across multiple mission phases and missions?
Autonomy	How may we increase effectiveness by local ‘decision-making’ by people and machines to minimize round-trip-light-time (RTLT) delays?
Precision Access	How may we realize more effective surface missions across multiple landings at diverse sites?
Virtual Presence	How may we increase the effectiveness of mission operations by enabling remotely located scientists to be ‘virtually present’?
Space Resources	How may we employ local resources to allow future exploration mission to accomplish much more than would otherwise be possible?

Technology Challenges for Future Systems:

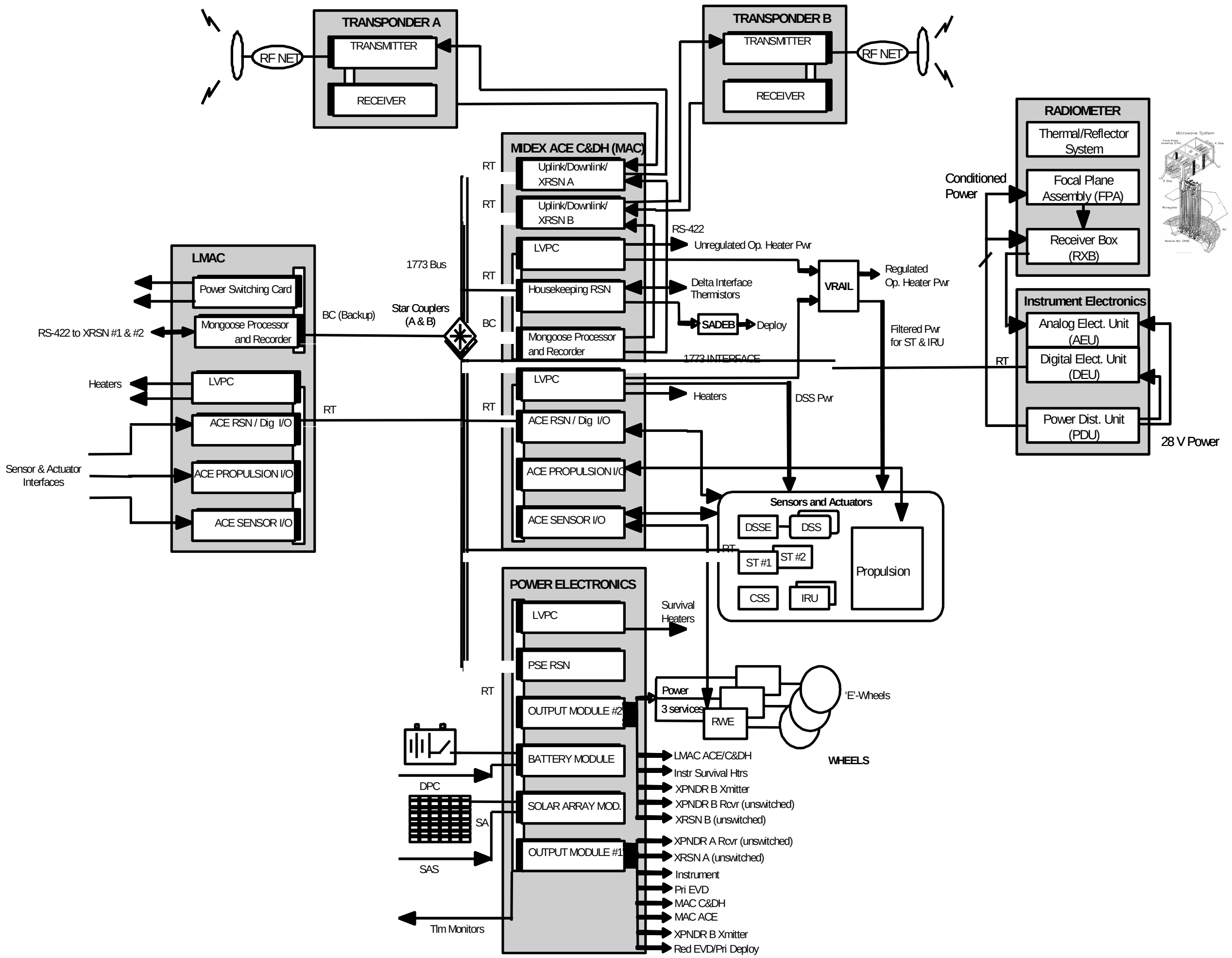
- **Intelligent Modular Systems**. This technology theme will involve development and demonstration of a range of reconfigurable, modular space subsystems, evolvable systems and systems of systems and others.
- **Robust & Reconfigurable Habitation Systems**. This theme will pursue the integrated demonstration of novel habitat concepts with other key subsystems such as life support, environmental monitoring and control, radiation protection, and others.
- **Integrated System Health Management (ISHM)**. This technology theme will involve integrated development and validation of sensors, software and computing to enable the monitoring and management of diverse subsystems/systems within future exploration vehicles and systems of systems.
- **Communications Networks and Systems**. This theme includes the development and integrated demonstration of novel high-bandwidth communications systems (including RF and optical communications approaches, supporting data processing/compression and software); also including demonstration of wireless and other approaches to local area and intra-vehicle network communications within the context of modular space systems architectures.

Novel Platform Systems Concept Demonstrations.
This theme will enable the development and validation of highly novel new technologies that have the potential to enable major, systems-of-systems level innovations related to traditional platform functions.

First Steps

- **Adopt *commercial interface standards***
  - Modify only as needed for space applications
- **Define *system architectures* that support the paradigm**
- **Select *choice technologies* that support the system architecture**
- **Standard Interfaces:**
  - Reduce Integration & Test times
  - Allows for maximum flexibility in component choices
  - Increase application breadth
  - Allows for individual component technology evolution
- **Choice Technologies:**
  - Increase mission implementation speed
  - Periodically revised list allows for technology evolution

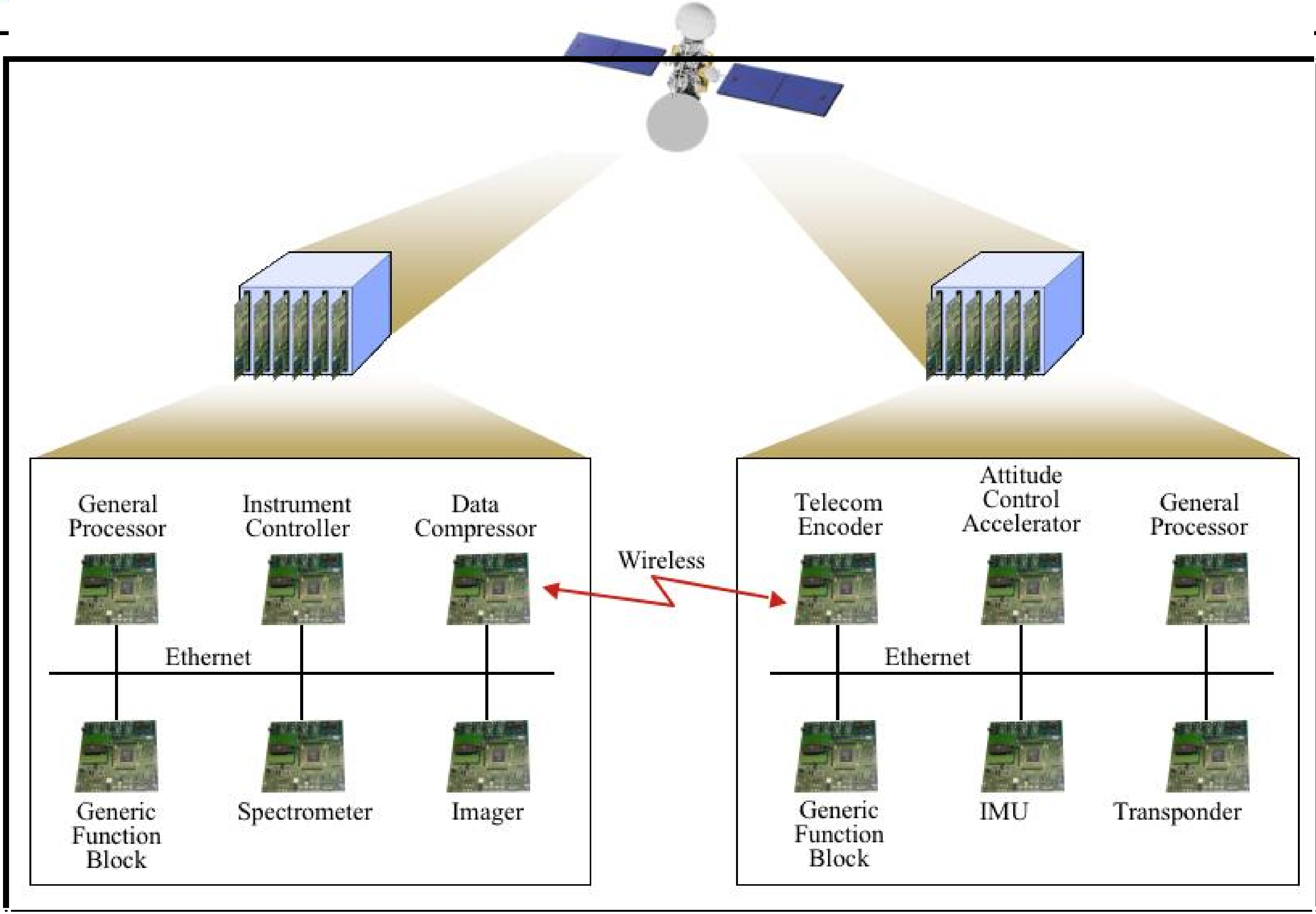
Distributed S/C Architecture



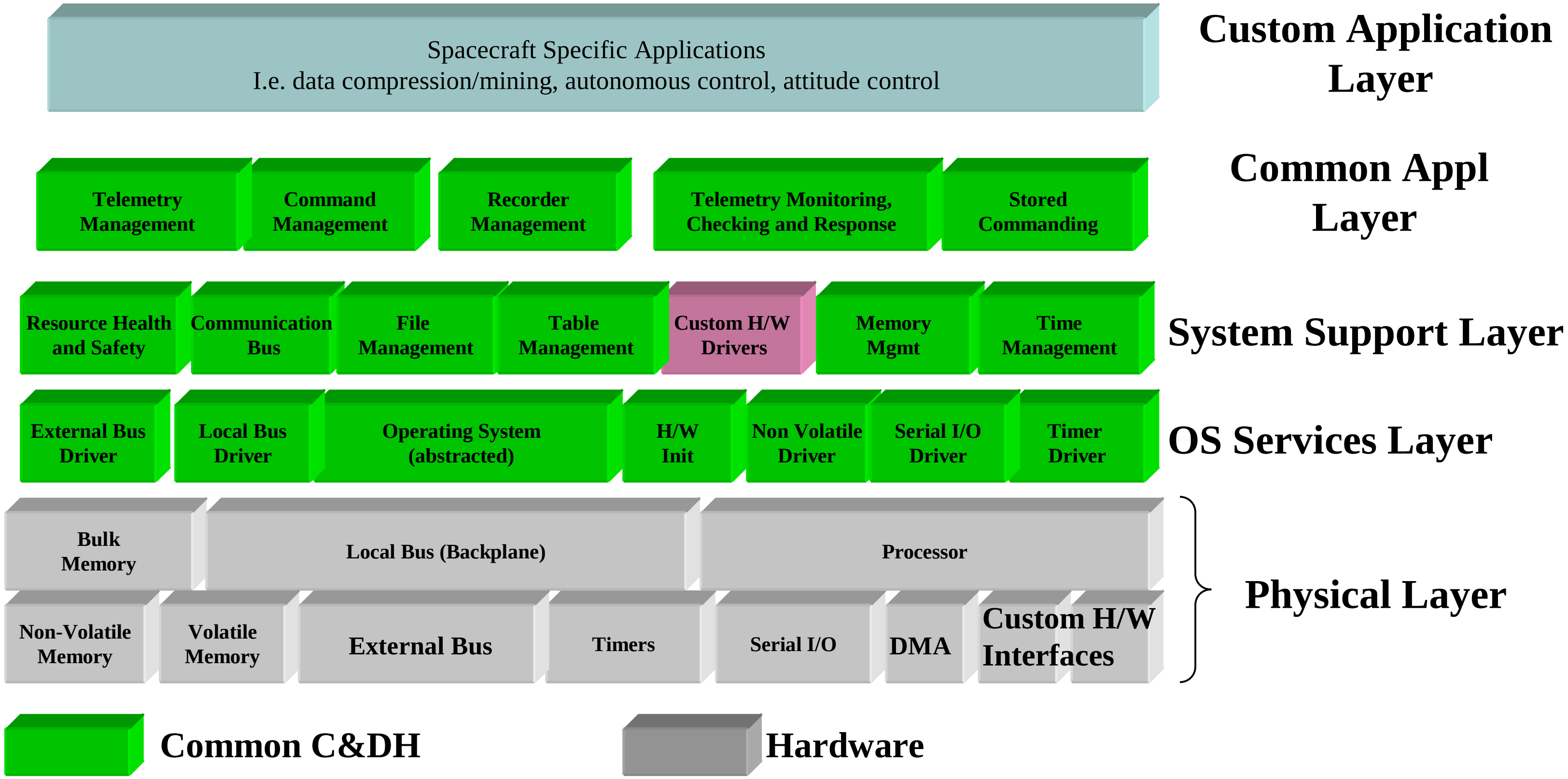
Breakdown of a spacecraft – H/W

- **Standardize at what level?**
  - System(s)
    - ü Constellations, multi-mission
    - ü Networks
  - Subsystems
    - ü Power box, ACE, Comm, Payload electronics
  - Device/component
    - ü PCI, 1553,Ethernet,USB,SpaceWire, etc.

Reconfigurable Avionic System with generic



Flight Software Layered Architecture



Software & Standards

- **Standard applications with APIs?**
  - (Microsoft has hundreds of APIs)
- **Abstracted ROS – use POSIX**
- **Device drivers**
- **What communication protocol? CCSDS? COTS middleware?**
- **What data formats? XML**
- **Open Source desirable**

Challenge

- **System Level**
  - Communication/data protocols/formats
    - ü IETF, CCSDS, COTS middlewares, XML
  - Breakdown into ISO 7 Layer Model?
- **Subsystems**
  - No software standards/format descriptions defined for spacecraft subsystems. Should an API for each subsystem be defined?
- **Device/Components**
  - Protocols defined at data link/physical layers. Other layers not always defined, leading to different software implementations.
  - Commercial/industry standards may be “overkill” for space applications, using more resources than available.

General S/W Issues

- How to deal with redundancy, especially hot backups
- Impact of standardization on performance
- Potential cost in non-volatile memory to support a variety of “device drivers”
- Maintaining core competencies in electronics design and development – does standardization curtail engineering creativity?
- Reliability – busses differ in degree of reliability
- Communications protocols – what to use!

Necessary Environment

- **Industry /Academia involvement**
- **Government direction after listening to the various voices**
- **Overall agreement and understanding of objectives by all concerned**
- **Move to implementation**

Communication leads to understanding

Understanding translates to action

Exploration needs action

Summary Observations

"Preparing for exploration and research accelerates the development of technologies that are important to the economy and national security. The space missions in this plan require advanced systems and capabilities that will accelerate the development of many critical technologies, including power, computing, nanotechnology, biotechnology, communications, networking, robotics, and materials."